

Five ADPs were deployed. Three of the five ADPs were configured with optional external sensors. One ADP was configured with a Sea-Bird Electronics, Inc., MicroCAT, and two ADPs were configured with Paroscientific, Inc., digi-quartz pressure sensors. Equipment locations, sampling configurations, and mounting parameters are summarized in Table 4-3. Current stations that included directional wave measurements (entrance gauges – Stations 1, 2, and 3) were set to record 10-min averages, once every 20 min, and averages were centered on the top of the hour. ADPs configured with a digi-quartz pressure sensor (back-bay gauges – Stations 4, 5, and 13) were set to record 3-min averages, once every 6 min, and averages were centered at the top of the hour.

Currents were also incorporated in the directional wave measurements discussed in the wave measurement section. Three ADVOcean gauges were deployed at Stations 1, 2, and 3, and the sampling volume was located approximately 1 m above the seafloor.

### **Data reduction and quality control procedures for moored current meters**

The current meter data were processed with a combination of manufacturer and in-house programs. Both ADPs and ADVOcean recorded in binary format. Following instrument retrieval, data files were downloaded and converted from binary to text (ASCII) file format. Subsequent data processing for the two instrument types involved different procedures as described in the following paragraphs.

Initial quality assurance/quality control (QA/QC) procedures for the ADP current meters were to generate amplitude data files for all beams and to inspect those files to verify that all current meters worked correctly. Pitch, roll, and heading data were then plotted to verify that the mooring remained upright and in place throughout the deployment. Each data file generated by SonTek software was then combined into one file to display the data as profiles. The ADPs were set to profile beyond the anticipated water depth to ensure that tidal fluctuations were included in the data. Profiles were edited to remove the erroneous data beyond the water depth by reference to both the pressure readings from the ADP or ADVOcean (if no pressure sensor was available on the ADP) and the recorded ADP beam amplitude data. The beginning and end of each file were removed for any data collected while the moorings were not deployed. Direction values were converted from degrees magnetic to degrees true north, decimal Julian dates calculated, and profiles vertically averaged. The vertically averaged profiles were then sent to the CHL FTP site.

The ADVOcean current meters were set to sample in burst mode for 4,096 data points at 2 Hz, once an hour. Bursts were averaged to obtain one reading per hour, and directions were converted from degrees magnetic to degrees true north. The beginning and end of each file were removed if data were collected while the instruments were not in the water. Averaged data were merged with the header files to add a time stamp to the record, and decimal Julian days were calculated prior to sending the data to the CHL FTP site.

For a final check of the data, vector time series plots were generated for each station location. Each plot contained vectors for the averaged ADP profile, the bottom ADP bin, and the averaged ADVOcean data where applicable (Stations 1, 2, and 3).

In addition to current measurements, the ADP at Station 1 had a MicroCAT installed, which measured conductivity and temperature. Temperature and conductivity values were recorded at the beginning of each sample interval and stored in the header file. Salinity values were calculated, the measurements were time stamped, and the data files transferred to the CHL FTP site.

### **General properties of the moored current meter data**

Table 4-5 shows 28-day statistics for Deployments 1, 2, and 3 for both the ADP and ADVOcean current meters. One should note, for Deployment 1, the statistics calculated were for 15 days because of the short deployment length, and caution is warranted when comparing these values with the 28-day averages for Deployments 2 and 3. Data quality was good with two exceptions: (a) Mooring 5 during Deployment 1 tipped over after day 3, and the current data are unusable following this event, and (b) the ADVOcean at Station 3 Deployment 1 and Station 1 Deployment 2 flooded, rendering the compass unusable. Data were corrected by using the compass values from the ADP mounted on the tripod above the ADVOcean, and incorporating the ADP compass values to calculate velocities referenced to earth coordinates.

Measurements of the current at the five stations within Willapa Bay show both site-specific and seasonal trends. Beginning with the seasonal trends, there was generally a small increase in the velocity with each successive deployment at all stations over the months of August through November.

As will be further discussed in the section, “Meteorology,” measured wind speed increased over the months of August through November (Figures 4-22 through 4-25). Periods of stronger wind are evident in the current records. Three events of note occurred during 16-19 September, 1-4 October, and 12-17 November. All winds were from the south, producing northerly flowing currents. The exception to this was Station 5, which showed little or no visible influence of wind, but this station is well protected in the south end of the bay.

Direction of the current was site specific. The current at Station 1 had a north-south flow, exhibiting an alongshore flow pattern. Station 1 was also influenced by the prevailing wind. As the wind direction changed during the deployment months from northerly to southerly, the current flowed predominantly to the north in October and November. Directions of the current for Stations 2 and 3 were roughly mirror images of each other. Station 2 had a northwest to southeast flow pattern, and Station 3 had a southwest to northeast flow pattern. The measurements for both stations were strongly influenced by their location within the Middle Channel and their proximity to the surrounding shoals. Station 4, located near the entrance to Willapa River, had an east-west flowing current, which would be expected because of the orientation of the river. The current at Station 5 in Nahcotta Channel was directed southwest and northeast, which was consistent with the orientation of the channel.

<b>Table 4-5 Statistics for Current Records</b>											
<b>Deployment No.</b>	<b>Site No.</b>	<b>Start Date</b>	<b>End Date</b>	<b>Mean Temp deg C</b>	<b>Residual E-W Current cm/sec</b>	<b>Residual N-S Current cm/sec</b>	<b>Mean Speed cm/sec</b>	<b>Maximum Speed cm/sec</b>	<b>Residual Speed cm/sec</b>	<b>Net Direction deg True North</b>	<b>Total Variance cm<sup>2</sup>/sec<sup>2</sup></b>
1 (15 day)	ADP1	08/26/98	09/10/98	8.8	3.7	0.4	12.4	46.5	3.7	84	182
	ADV1	08/26/98	09/10/98	8.7	2.4	-0.6	8.3	33.0	2.5	103	94
	ADP2	08/26/98	09/09/98	11.3	-14.1	6.1	47.1	153.5	15.4	293	3,091
	ADV2	08/26/98	09/09/98	11.1	-12.4	4.1	42.9	152.1	13.1	288	2,565
	ADP3	08/26/98	09/09/98	11.6	6.7	-1.4	47.7	126.0	6.9	101	2,991
	ADV3	08/26/98	09/09/98	11.7	1.4	-2.2	41.1	109.0	2.6	147	2,181
	ADP4	08/26/98	09/09/98	15.1	3.7	1.6	37.8	93.4	4.0	67	1,897
	ADP5	08/26/98	09/09/98	Mooring turned over near beginning of deployment - no available data							
2 (28 day)	ADP1	09/11/98	10/08/98	10.9	-1.2	3.7	14.4	80.1	3.8	342	304
	ADV1	09/11/98	10/08/98	10.7	-1.0	0.3	9.6	69.4	1.0	285	180
	ADP2	09/11/98	10/07/98	12.3	-8.0	5.3	44.9	167.8	9.6	303	2,716
	ADV2	09/11/98	10/07/98	12.2	-6.0	4.7	29.2	137.1	7.7	308	1,317
	ADP3	09/11/98	10/07/98	12.6	8.7	-1.1	46.8	115.4	8.8	96	2,789
	ADV3	09/11/98	10/07/98	12.4	4.5	-2.3	36.3	88.1	5.0	117	1,673
	ADP4	09/10/98	10/05/98	14.4	-3.0	1.2	37.1	103.1	3.3	292	1,842
	ADP5	09/11/98	10/08/98	16.4	-0.2	-0.3	36.9	86.4	0.4	216	1,644
3 (28 day)	ADP1	10/10/98	11/06/98	12.8	0.3	4.8	16.2	65.4	4.8	4	331
	ADV1	10/10/98	11/06/98	12.7	-0.8	4.2	11.2	53.8	4.3	349	183
	ADP2	10/15/98	11/11/98	12.8	-8.5	9.8	51.5	196.1	13.0	319	3,478
	ADV2	10/15/98	11/11/98	12.6	-3.9	11.2	39.4	154.3	11.8	341	2,181
	ADP3	10/14/98	11/10/98	12.8	-2.9	-5.5	54.0	165.9	6.2	208	3,699
	ADV3	10/14/98	11/10/98	12.6	-4.3	-4.5	43.1	133.5	6.3	224	2,346
	ADP4	10/14/98	11/10/98	13.0	-5.3	0.9	38.4	122.4	5.4	280	2,008
	ADP5	10/15/98	11/11/98	12.6	-0.6	-1.4	34.9	87.2	1.5	202	1,483

### ADCP transect cruises

Over-the-side Doppler current measurements were collected in mid-November 1998 during a spring-tide condition. Measurements of the current were made in conjunction with the profiling CTD cruise. The purpose of the over-the-side current measurements was to obtain discharges across the various channels at the mouth and head of the bay during both ebbing and flooding tides. The discharges indicate the net movement of water into and out of the bay. In addition, the transect measurements provide information on the regional variation of the current structure across the channels.

An RDI Broadband 600-kHz ADCP was mounted on the port side of a vessel during transects across the bay. Navigation information was obtained with a Trimble GPS station with differential capabilities. Configuration of the ADCP for the cruise is detailed in Table 4-6. Setup of the instrumentation occurred on 16 November. Communication with all systems was verified, and configuration files were created.

**Table 4-6**  
**ADCP Configuration Parameters**

Parameter	Value
Cell (bin) size	0.5 m
Blank after transmit cell size	0.5 m
Pings per ensemble	4
Time between pings	0 sec
Average (ensemble) interval	4 sec
Magnetic offset	19 deg
Maximum bottom tracking depth	30 m

Transect cruises were conducted on 17-18 November 1998. Current data were collected in three geographic regions displayed in Figure 4-8. Transects in the south bay across Nahcotta and Stanley Channels were obtained on 17 November. Fifteen transects were measured across the south bay (Figure 4-9). Visibility was low during the first 2 hr of data collection because of fog. Difficulties were also encountered during the first day when navigation data were not collected by the data acquisition software. Bottom tracking was functional, so ship speeds were still subtracted from the recorded current measurements. As a backup for the lost navigation data, time and ship position displayed on the GPS were handwritten in a field log at approximately 5-min intervals. Positions were recorded by hand along all transects during the remainder of the cruise. Total discharge as reported on the display monitor was noted in the field log for each transect.

Transects 1 through 12 were traversed during the flood tide, and Transects 13 through 16 were traversed on the ebb tide (note: there is no Transect 2). Transits across the south bay on the ebb tide were frequently split into two transect files because of the presence of a shoal between the two channels. The depths over the shoal were generally too shallow for the ADCP to collect data. Transects on the flood tide were located further north than the ebb-tide transects because the water at the original transit area was too shallow for the boat to safely operate without grounding. Because of the northern location of the flood tide transects, measurements were possible across the complete channel without having to split the transect into two separate files.

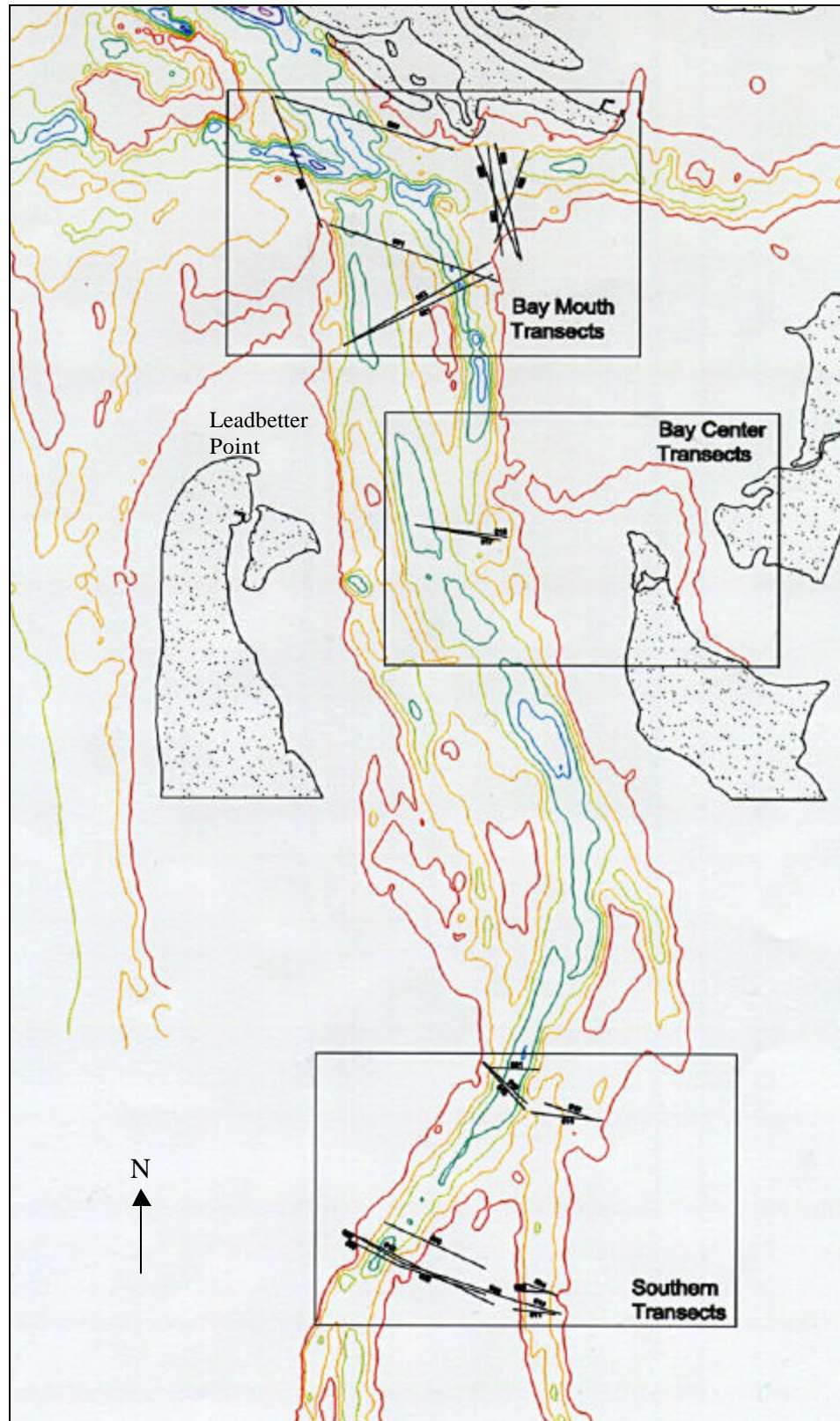


Figure 4-8. ADCP transects in Willapa Bay, 17-18 November 1998

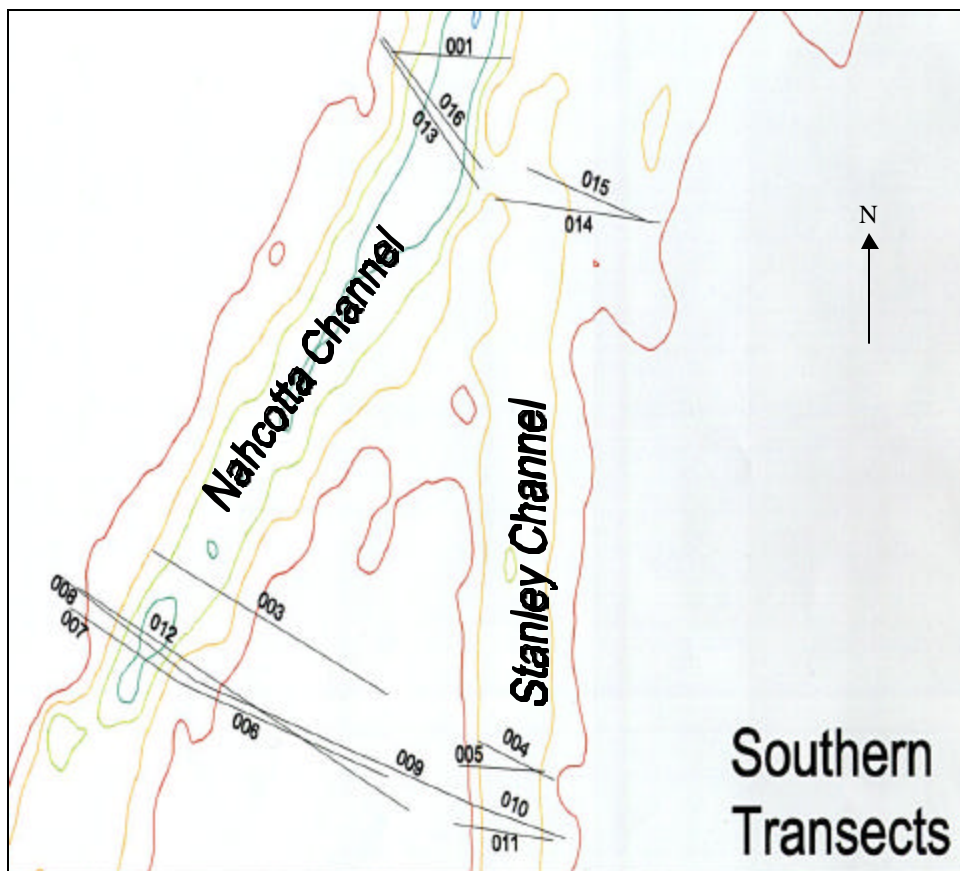


Figure 4-9. ADCP transects in southern Willapa Bay, 17 November 1998

The final two transects on 17 November (17 and 18) were made outside the entrance to Bay Center (Figure 4-10).

Transects near the mouth of the bay were obtained on 18 November. Nine transects were made on this date, five on the morning flood tide and four on the afternoon ebb (Figure 4-11). Because of the wave action and exposed shoals during the early part of the flood tide, transects were completed across the mouth of the Willapa River (Transects 23, 25, and 26) and across the entrance to the southern channels (Transects 21 and 22). On the ebb tide, with higher water levels and calmer seas, a box pattern of transect measurements was obtained at the mouth of the bay (Transects 29 through 32). Problems were encountered occasionally with bottom tracking during times of stronger current. When bottom tracking was lost, navigation was recorded; thus, ship motion was continually subtracted from the measured currents.

#### **Data reduction for ADCP transect cruises**

Data were collected and partially processed with RDI Transect software that accompanies the ADCP. ASCII profiles created in Transect were further manipulated with EHI software to produce depth-averaged vectors with location fixes for each profile.

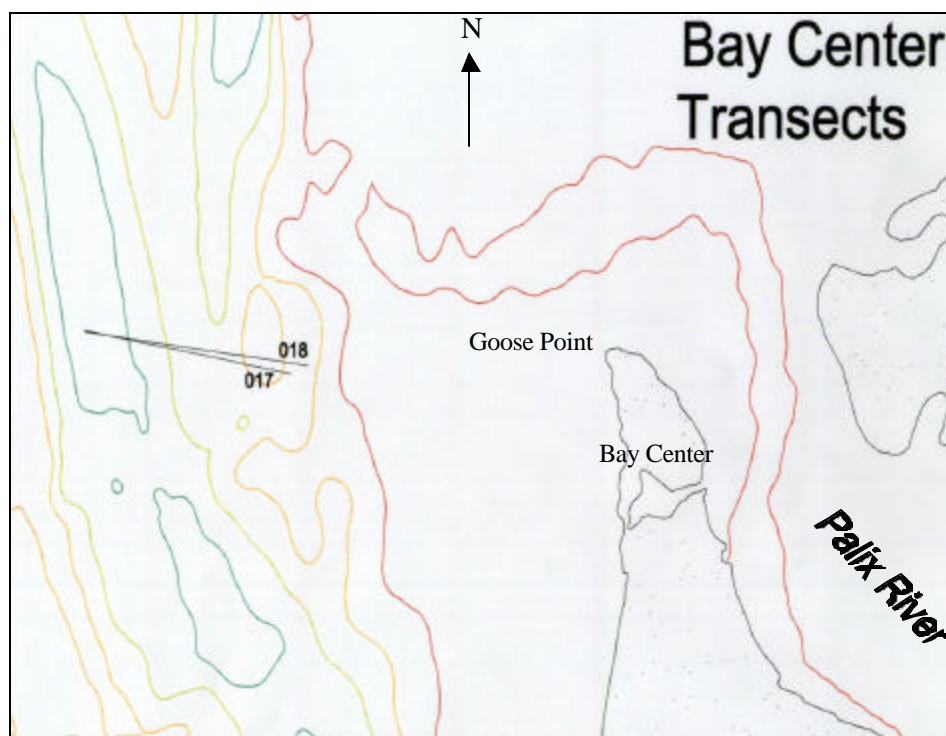


Figure 4-10. ADCP transects near Center Channel, Willapa Bay, 7 November 1998

RDI Transect calculates values for discharge along a channel section while the ship is underway. These values were recorded in the log at the conclusion of each channel-crossing transect. Two methods were used to fix the profile locations. Transects 1 through 23 use bottom track information to find location. Transects 25 through 32 use GPS coordinates to record location.

For Transects 1 through 23, current speed was obtained by removing the bottom-track velocity, but no coordinate stamps were recorded in the profiles. Transect software records bottom-track displacement north ( $\Delta N$ ) and displacement east ( $\Delta E$ ) with each profile. Consulting logged coordinates for the beginning of each transect made correcting possible by the  $\Delta N$  and the  $\Delta E$  values recorded for a profile to arrive at a location for that profile.

Transects 25 through 32 had GPS coordinate stamps in the ADCP profiles. These coordinates were read for each profile and reissued with the depth-averaged values in the final output. Speed and direction were plotted for each transect to verify that software output conformed to expected values. Attention was focused on transects with reciprocal tracks to verify that ADCP head-alignment corrections were accurate, giving similar current profiles on all courses.

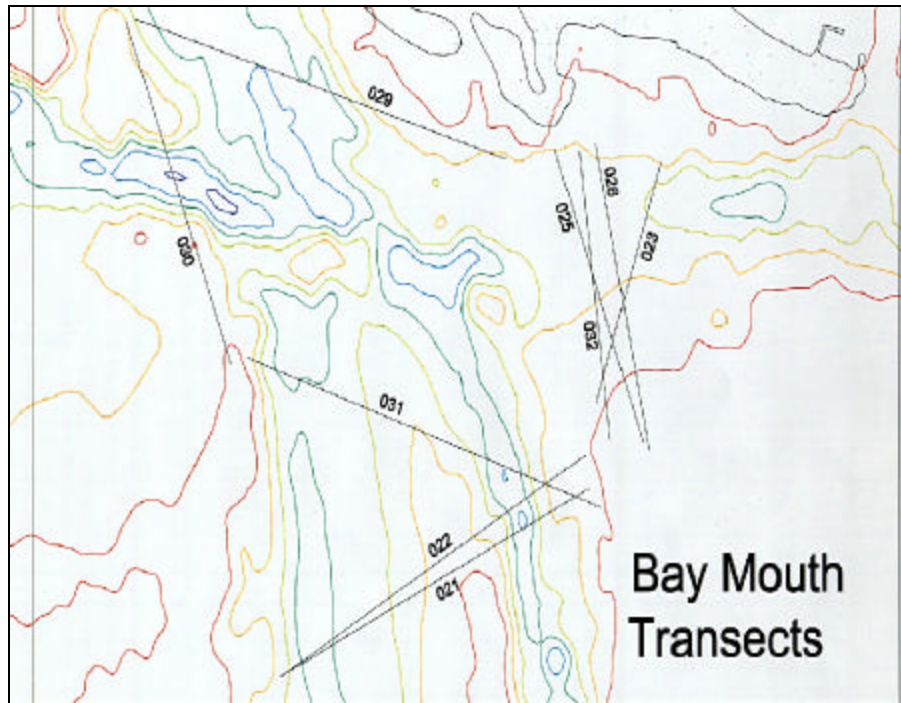


Figure 4-11. ADCP transects at entrance of Willapa Bay, 18 November 1998

### General properties of the ADCP transect data

As noted in the “ADCP transect cruises” section, the ADCP transects were collected during a spring tide the week of 16 November (Figure 4-12). Figure 4-13 provides an expanded view of the water-level variation for the data collection days, with markers indicating at what tidal stage each transect was measured. For both days, approximately the same number of transects were traversed on the flood tide as for the ebb tide. Transport and regional current structures for each measurement day are reviewed in the following paragraphs.

Discharge is defined as the total volume of water flowing through a cross section. The ADCP measures discharge in cubic meters per second for each ensemble and yields a sum of the discharge for each transect. Table 4-7 lists the summed discharge values for each transect measured at the southern end of the bay. Negative discharge indicates southward or flooding flows, and positive discharge indicates northward or ebbing flows. For the location of each transect, refer to Figure 4-9. The tidal height referenced to meters mllw at the beginning of each transect is also listed in Table 4-7.

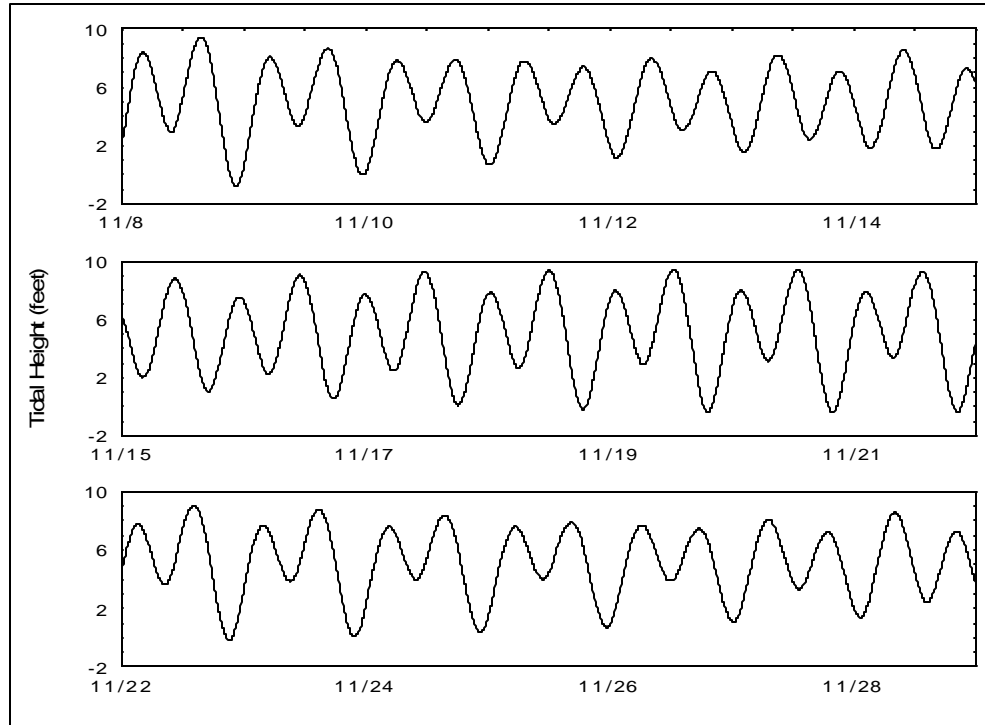


Figure 4-12. Predicted tide for 3 weeks in November 1998

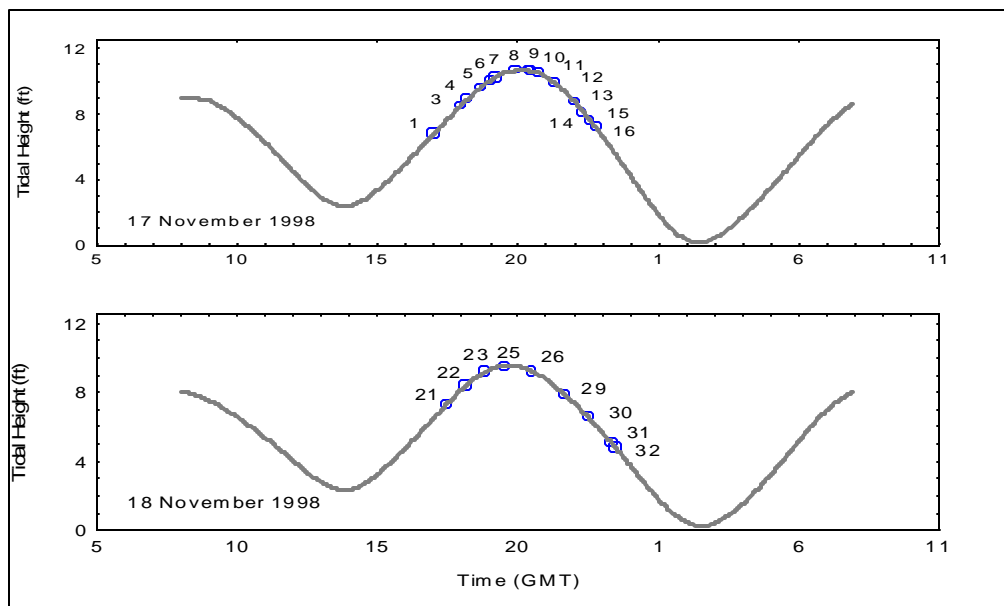


Figure 4-13. Water level for ADCP transect collection days (circles denote tidal stage each transect was collected, and numbers refer to transect number)

<b>Table 4-7 Discharge Values for South Willapa Bay</b>			
<b>Transect Number</b>	<b>Location Description</b>	<b>Discharge, cu m</b>	<b>Tidal Height, m (mllw)</b>
1	South Channel	-9,407	2.07
3	Nahcotta Channel	-7,585	2.59
4	Stanley Channel	-3,781	2.71
5	Stanley Channel	-3,340	2.93
6	Shoal Area	-990	3.05
7	Nahcotta Channel	-3,472	3.11
8	Nahcotta Channel	-2,320	3.26
9	Shoal Area	870	3.26
10	Stanley Channel	-61	3.23
11	Stanley Channel	664	3.20
12	Nahcotta Channel	6,404	3.02
13	South Channel	8,718	2.65
14	South Channel	5,802	2.47
15	South Channel	5,873	2.32
16	South Channel	9,801	2.19

Discharges summed across all channels on the mid-ebb and flood tides were approximately equal. For example, Transects 1 and 16 were collected near the same location at roughly the same stage on the flooding and ebbing tides, respectively. The sums of other transects indicate this same result. The total for Transects 5, 6, and 7 on the flooding tide equals -7,802 cu m/sec, and the total for Transects 11 and 12 on the ebbing tide was +7,068 cu m/sec.

The shoal area between Nahcotta and Stanley Channels showed smaller discharges than expected. It also exhibited the first ebbing discharge values (Transect 9) while the two channels were still flooding (Transects 8 and 10).

Depth-averaged current speed across Stanley Channel ranged between 10 and 60 cm/sec, with peak speed reaching about 70 cm/sec. The current range had less variability for the Nahcotta Channel at 30-50 cm/sec with peaks reaching about 75 cm/sec. Current speed to the north of both channels ranged from 40 to 80 cm/sec with peaks reaching 100 cm/sec.

Table 4-8 lists the summed discharge values for the transects measured at the north end of the bay. Transect locations are displayed in Figure 4-11.

<b>Table 4-8 Discharge Values for North Willapa Bay</b>			
<b>Transect Number</b>	<b>Location Description</b>	<b>Discharge, cu m</b>	<b>Tidal Height, m (mllw)</b>
21	Southern Mouth	-27,042	2.23
22	Southern Mouth	-28,079	2.56
23	Willapa River	-8,872	2.80
25	Willapa River	-6,308	2.90
26	Willapa River	1,033	2.80
29	Outer Mouth	14,472	2.41
30	Outer Mouth	11,520	2.01
31	Southern Mouth	23,008	1.55
32	Willapa River	10,530	1.46

Discharge at the mouth of the bay shows the same directions as that for the southern bay, outbound on the ebb tide and inbound on the flood. One major difference was the magnitude, which showed a factor of 10 increase. Comparisons between the ebb- and flood-tide discharges were more difficult to

make for this area because of the inability to occupy all transect areas during the same phase of the tide. However, some general comparisons can be made. For example, discharges for Transects 21 and 22 compared reasonably well with discharge for Transect 31. Similar comparisons can be made between Transects 23 and 26 at the mouth of the Willapa River.

Increases in the current at the bay entrance as compared with the southern transects of the previous day were also evident. Current speed on transects across the southern mouth ranged between 50 and 120 cm/sec. Current speeds across the mouth of the Willapa River were in the range of 20 to 100 cm/sec, averaging around 50 cm/sec. The least variable current speeds across transects were seen at the outer mouth area. Current speed for Transects 29 and 30 ranged between approximately 60 and 80 cm/sec.

## Water Level and In Situ Conductivity and Temperature Measurements

Much of the water exchange between Willapa Bay and the Pacific Ocean is tidally driven, and any quantification of the flow in the bay will depend upon the predicted tide level throughout the bay.

### Instruments and field procedures

Conductivity, temperature, and pressure data were collected using Sea-Bird Electronics, Inc., SBE 26-03 tide gauges. Tide gauges were installed at Stations 6, 7, 8, and 9 (Figure 4-1 and Table 4-9).

Gauges were set to record 3-min averages every 3 min. Three-minute averages were synchronized to logging times of the four gauges to begin at 01:30 min before the hour so that the first average each hour centered at the top of the hour.

<b>Table 4-9</b>					
<b>Water Level Station Locations and Measured Parameters</b>					
Station Number	Location Description	Latitude deg N	Longitude deg W	Elevations Relative to Toke Point, m (mllw )	
				Sensors	Bay Floor
6	South Bend	46 40.110	123 48.771	-1.276	-1.65
7	Nahcotta	46 30.098	124 01.430	-0.632	-1.15
8	Naselle River	46 25.794	123 54.374	-1.674	-2.13
9	Bay Center	46 37.404	123 56.844	-1.762	-3.13

Gauges were mounted on pilings in swinging pipe brackets that allowed servicing without diving. Work on the gauges was done in small boats by swinging the pipe up and away from the base of the piling. After data download and battery change-out, the pipe was returned to vertical with the gauge reoccupying the elevation prior to servicing. All tide gauge mounts performed well over the duration of the project with no slippage relative to the pilings.

## Data reduction

Water levels at Stations 6, 7, 8, and 9 were derived from subsurface pressure records. This derivation was made using the United Nations Educational, Scientific and Cultural Organization (UNESCO) 1983<sup>1</sup> equation of the state for seawater density. Water level was then referenced to Toke Point mllw datum using offsets measured during a leveling survey of the gauge locations relative to National Geodetic Survey benchmarks.

## Tide gauge water level

Total pressure (barometric pressure plus water pressure) was recorded at each water-level station, and barometric pressure was logged hourly at the EHI meteorological station in the Bay Center Channel. During data processing, atmospheric pressure values were subtracted from the recorded water-level data.

The equation of state of seawater was used to calculate local seawater density in the area of the gauge based upon measured gauge pressure, salinity, and temperature. Depth of the gauge was calculated from density, pressure, and gravitational acceleration for the 40°N latitude.

## Survey to Toke Point datum

The leveling survey accessed in this study was performed by the Washington Department of Ecology (WDOE).<sup>2</sup> In summary, water level at marked times was surveyed to the North American Vertical Datum of 1988 (NAVD 88) vertical datum by means of Real-Time Static GPS. Observations were taken to National Geodetic Survey (NGS) 2-cm standards using two control stations for each site. Each site was occupied twice over consecutive days.

An offset from NAVD 88 to Toke Point mllw was established by consulting published National Ocean Service (NOS) and NGS data sheets. The end product of this survey was water-level height to Toke Point mllw established at each site for a known time.

## Gauge water level to Toke Point datum

By taking the water-level record from a tide gauge for the time of the elevation water-level survey to Toke Point mllw, it was possible to create an individual offset for each tide gauge, correcting the gauge-derived water level to a Toke Point mllw reference. This correction based on observed conditions at a known time was unique to each gauge installation and provided consistent reference regardless of hydraulic conditions within the individual pressure cell.

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<sup>1</sup> Fofonoff, N. P., and Millard, Jr., R. C. (1983). "Algorithms for computation of fundamental properties of seawater," UNESCO technical papers in *Marine Science* 44.

<sup>2</sup> Daniels, R. (1998). Letter report to Evans-Hamilton, Inc. on the Washington Coastal Gauge Control Project as part of a U.S. Army Corps of Engineers study on Willapa Bay, p. 14.

With this process, it was possible to reference all four tide measuring gauges to an existing mllw datum at Toke Point with the assumptions that water density above the gauge was homogenous and that barometric pressure was stable over a 60-min period.

### **Data trends**

Data from all water-level gauges were plotted after processing to observe trends and check quality. Figure 4-14 shows a sample plot of Deployment 4 at Station 9.

Processed data showed strong tidal signals in salinity and temperature at river Stations 6, 8, and 9. Station 7 in Nahcotta Harbor showed less variance in salinity and temperature.

Unknown factors periodically dampened tidal fluctuations in salinity at Station 6 in South Bend. Salinity became stable over several days and then returned to a tidally varying signal. Sensor malfunction is not the most likely source of unusual stability followed by a strong variance in amplitude. Other sources of this variance may be saline discharge from an adjacent oyster-processing industry or biological activity interfering with the flow of water through the conductivity cell. Little bio-fouling was noted on the water-level gauges at all stations.

## **Profiling CTD Survey**

### **Purpose of data collection**

Profiling Conductivity Temperature Depth (PCTD) data were collected to determine the vertical structure of the water column within Willapa Bay. PCTD casts were taken on high- and low-slack tides during a spring tidal sequence.

### **Instruments and field procedures**

Salinity data were collected with a Sea-Bird Electronics, Inc., SBE-19 Profiler. The conductivity cell, the temperature sensor, and pressure gauge had been calibrated within the preceding year. This instrument derived salinity from conductivity measurements; likewise, density was calculated from temperature and salinity.

All stations were sampled on both a high-slack and low-slack tide with the exception of Station 11, which was not sampled on a low-slack tide because of weather constraints. Pertinent station information is listed in Table 4-10. Station position was determined by means of differential GPS. In addition to stations within the bay channels, PCTD measurements were taken at the tide gauges. Once on station, the instrument was soaked at the water surface for roughly 3 min to allow the sensors to equilibrate. The instrument was then lowered through the water column at a rate of approximately 20 cm/sec, allowed to gently touch bottom, and then raised back to the surface. Data were downloaded at each station and checked in the field for data quality.

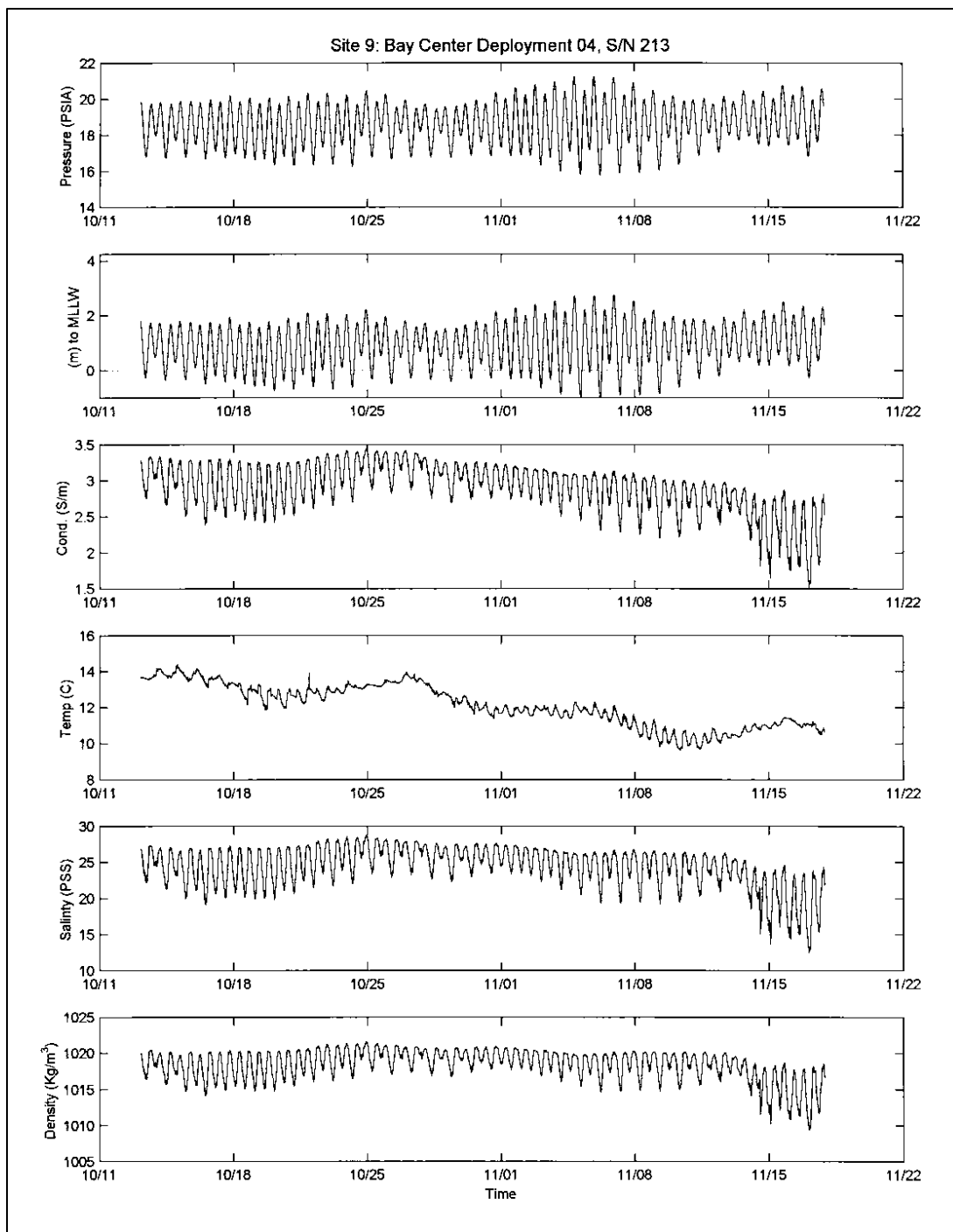


Figure 4-14. Example of tide gauge data, Station 9, Deployment 4

<b>Table 4-10 Profiling Conductivity Temperature Depth (PCTD) Survey Information</b>								
<b>Date</b>	<b>Time (downcast) GMT</b>	<b>Julian Day (downcast) GMT</b>	<b>Station No.</b>	<b>Tide</b>	<b>Latitude deg N</b>	<b>Longitude deg W</b>	<b>Maximum CTD Depth, m</b>	<b>Echosounder reading, m</b>
11/17/98	15:28:37	321.6448669	1	Low	46 40.133	123 48.710	6.5	7.0
11/17/98	18:46:24	321.7822164	1	High	46 40.133	123 48.710	9.0	9.1
11/17/98	15:11:07	321.6327141	2	Low	46 41.178	123 49.066	10.0	10.1
11/17/98	18:57:10	321.7896991	2	High	46 41.169	123 49.059	10.5	11.6
11/17/98	14:59:01	321.6243229	3	Low	46 42.447	123.50.884	8.5	8.5
11/17/98	19:10:13	321.7987616	3	High	46 42.454	123 50.891	10.5	10.4
11/17/98	14:35:04	321.6076852	4	Low	46 42.160	123 53.356	7.5	7.9
11/17/98	19:23:26	321.8079398	4	High	46 42.167	123 53.333	9.5	9.8
11/17/98	14:03:30	321.5857639	5	Low	46 41.606	123 55.678	6.0	13.5
11/17/98	19:37:48	321.8179109	5	High	46 41.617	123 55.655	9.0	9.1
11/16/98	20:45:51	320.8651736	6	High	46 41.895	123 58.128	13.5	14.0
11/16/98	23:06:53	321.0464468	6	Low	46 41.916	123 58.097	11.0	11.4
11/16/98	19:30:25	320.8127836	7	High	46 42.285	124 01.636	14.0	13.4
11/17/98	00:49:20	321.0342593	7	Low	46 42.270	124 01.609	11.0	11.6
11/16/98	19:55:25	320.8301447	8	High	46 43.436	124 03.718	25.0	27.4
11/17/98	00:34:06	321.0236806	8	Low	46 43.368	124 03.621	20.5	21.9
11/16/98	19:10:36	320.4656887	9	High	46 41.879	124 03.012	12.5	14.0
11/17/98	00:14:51	321.0103067	9	Low	46 41.843	124 03.121	10.0	10.1
11/16/98	18:30:26	320.7711285	10	High	46 40.382	124 00.775	9.5	9.8
11/16/98	23:50:18	320.9932581	10	Low	46 40.400	124 00.814	8.0	7.9
11/16/98	17:45:26	320.7398843	11	High	46 37.680	123 59.783	11.5	12.5
11/18/98	15:31:01	322.6465451	12	Low	46 35.065	123 58.068	16.5	16.5
11/18/98	19:56:09	322.8306597	12	High	46 35.052	123 58.060	18.0	18.1
11/18/98	15:51:02	322.660434	13	Low	46 33.546	123 56.756	10.0	10.4
11/18/98	20:11:56	322.8416204	13	High	46 33.531	123 56.758	12.0	11.6
11/18/98	15:14:15	322.63489	14	Low	46 32.067	123 59.025	14.0	14.3
11/18/98	20:36:25	322.8593171	14	High	46 32.072	123 59.060	16.0	16.5
11/18/98	16:19:24	322.6801331	15	Low	46 30.739	123 58.319	9.5	9.8
11/18/98	19:28:07	322.8111921	15	High	46 30.745	123 58.325	11.0	11.6
11/18/98	13:53:55	322.5791088	16	Low	46 30.096	124 01.431	3.0	3.0
11/18/98	21:37:09	322.9007986	16	High	46 30.103	124 01.430	5.0	4.0
11/18/98	14:31:20	322.6050926	17	Low	46 29.150	124 00.830	14.0	14.3
11/18/98	20:56:41	322.8726968	17	High	46 29.165	124 00.852	15.5	16.2
11/18/98	16:31:42	322.6886748	18	Low	46 29.192	123 57.797	11.5	11.6
11/18/98	19:14:41	322.8018634	18	High	46 29.172	123 57.795	7.5	13.1
11/18/98	16:44:24	322.6975	19	Low	46 27.978	123 56.486	17.0	17.4
11/18/98	19:00:12	322.7918056	19	High	46 27.935	123 56.453	19.5	13.1
11/18/98	14:48:49	322.617228	20	Low	46 26.723	124 00.300	15.0	14.9
11/18/98	21:11:48	322.8831887	20	High	46 26.738	124 00.301	17.0	17.7

## Data reduction

All data were processed with Sea-Bird software. Upcast data and data recorded while soaking were discarded, leaving the downcast data. Temperature, salinity, and density data were then averaged into 0.5-m bins to produce a profile corresponding to saltwater depth. These data were then averaged over the water column to produce a single datum. The profiles were graphed in Figure 4-15 through 4-21 to illustrate the water column structure and to verify data quality. In these figures, the plotted variable “PSS” represents practical salinity scale units, parts per thousand. The density is presented in  $\sigma_t$  values where  $\sigma_t$  = (water density - 1)  $\times 10^3$  g/cm<sup>3</sup>.

## Data properties

The salinity and density structure for the Willapa River (Stations 1 through 5) greatly differed between high and low tide (Figures 4-15 and 4-16). The freshwater lens was much larger throughout the river during the low slack than on the high slack. This lens persisted somewhat at Station 1 (South Bend) on the high slack, but was less than 2 m thick for the remaining stations. Temperature throughout the water column did not change.

Unlike the Willapa River stations, the vertical structure for sites within the central portion of the bay (Stations 12 through 14) remained largely unchanged between high- and low-slack tides. Although the profile shape did not change, the salinity during low slack was generally lower than on high slack (Figure 4-17). Salinity levels at stations in the Naselle River channel (Stations 15, 18, 19) varied between the tidal stages; much like the Willapa River stations, salinity was lower throughout the water column on the low tides (Figure 4-18). High-slack measurements showed little stratification within the water column. Nahcotta channel stations (Stations 16, 17, 20) showed little variation between high- and low-slack tides (Figure 4-19). Water temperature remained constant at all stations.

Vertical profiles for stations located in the northern portion of the bay (Stations 6 through 11) changed relative to their proximity to the Willapa River (Figures 4-20 and 4-21). Salinity and density values at Stations 6, 7, and 8 showed a lens on the low slack that was greatly diminished (Station 6) or gone (Stations 7 and 8) on the high slack. Stations farther removed from the mouth of the Willapa River showed little or no change between the two tidal stages. As with all other stations, temperature did not vary.

## Meteorology

### Instruments and field procedures

A Campbell Scientific, Inc., MetData 1 weather station was installed 12 August 1998 on the Bay Center Channel Light, Number 2 platform near the center of the study area (Figure 4-1). The MetData 1 weather station measured wind speed, wind direction, air temperature, and barometric pressure approximately 10 m above the water surface. All data were stored in a CR10 data-logger and retrieved approximately once a month (Table 4-1) using a portable computer.

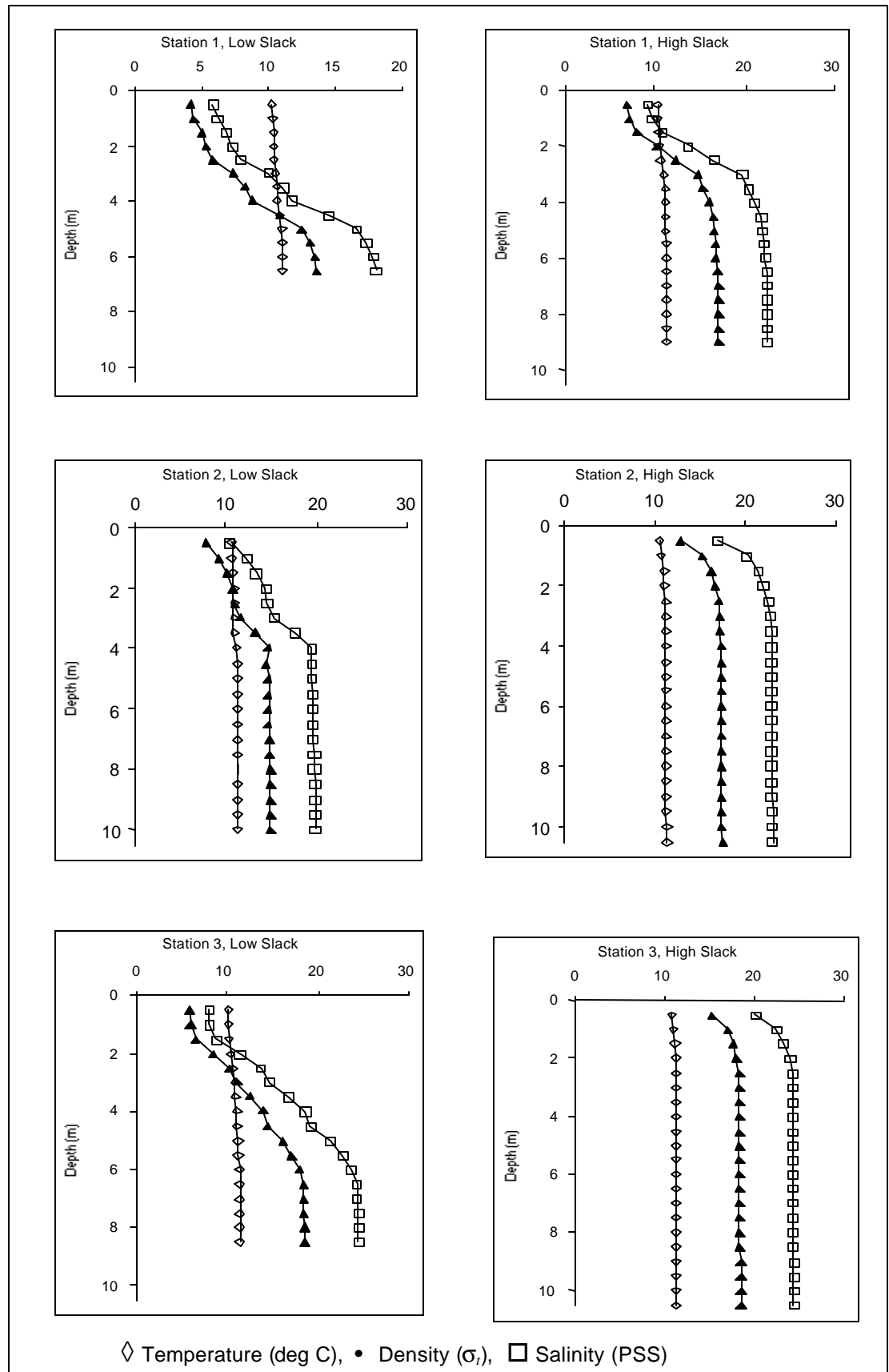


Figure 4-15. Temperature, density, and salinity profiles for stations in Willapa River during low- and high-slack tides (Stations 1-3)

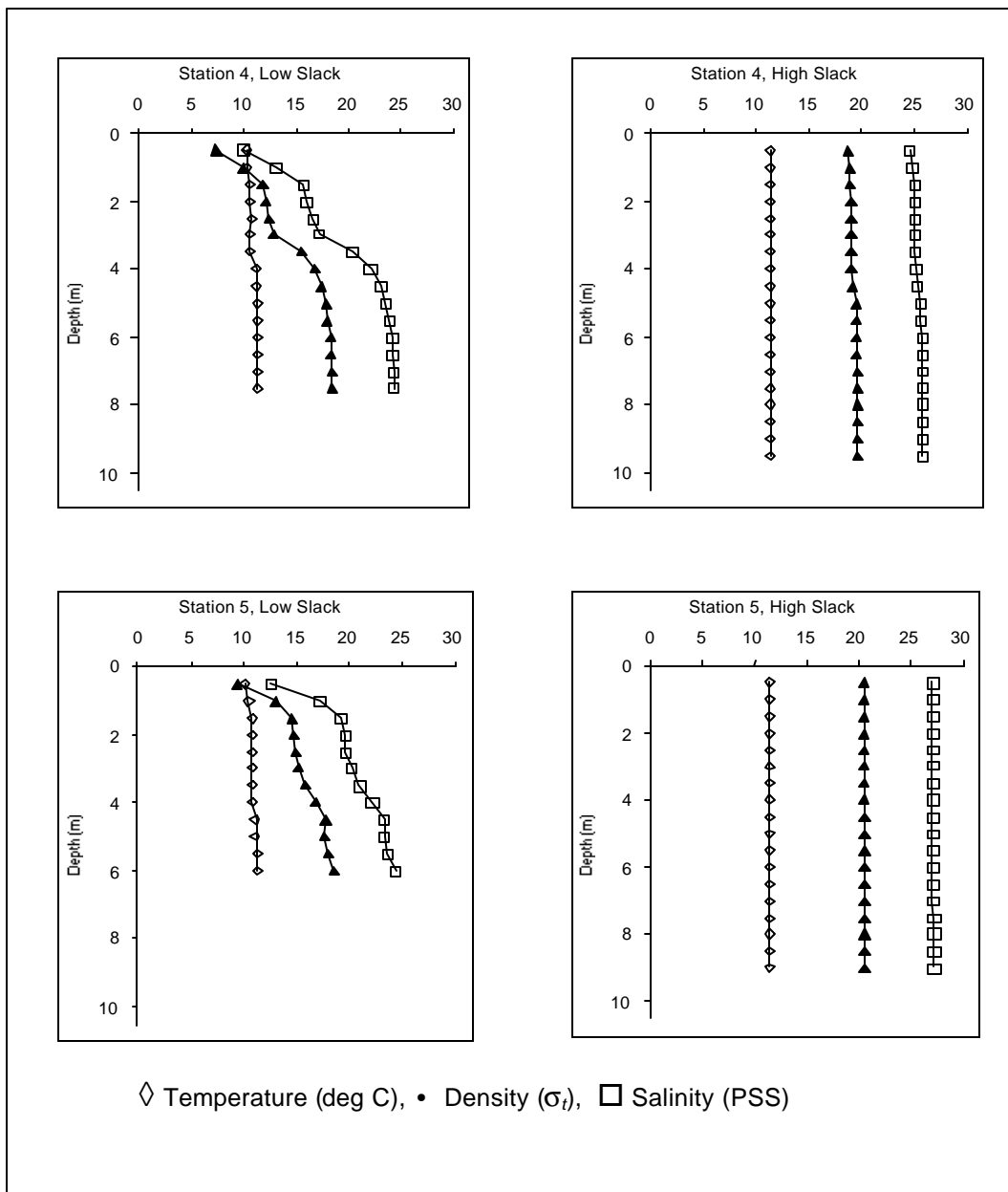


Figure 4-16. Temperature, density, and salinity profiles for stations in Willapa River during low- and high-slack tides (Stations 4 and 5)

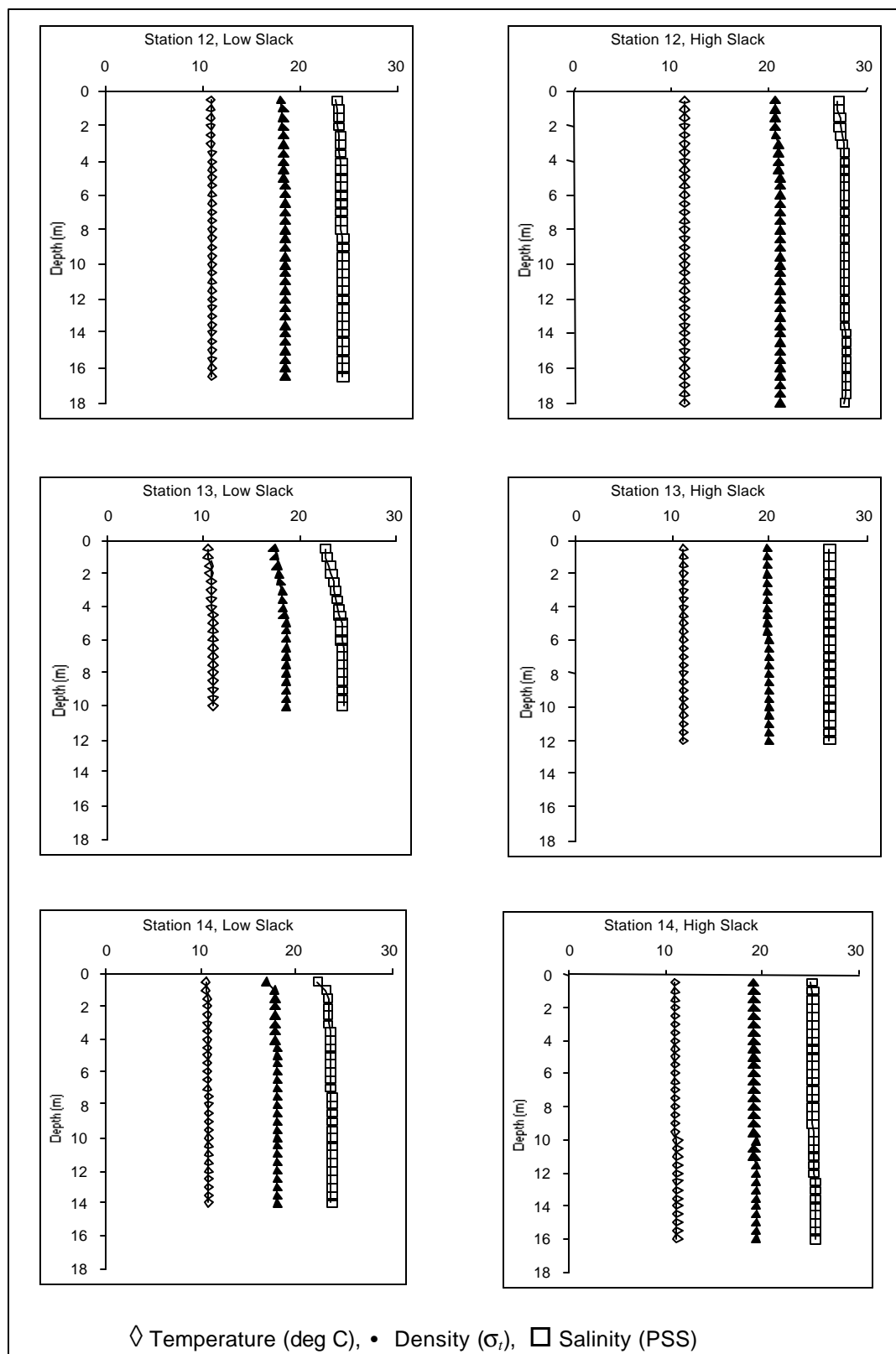


Figure 4-17. Temperature, density, and salinity profiles for stations in central Willapa Bay during low- and high-slack tides (Stations 12-14)

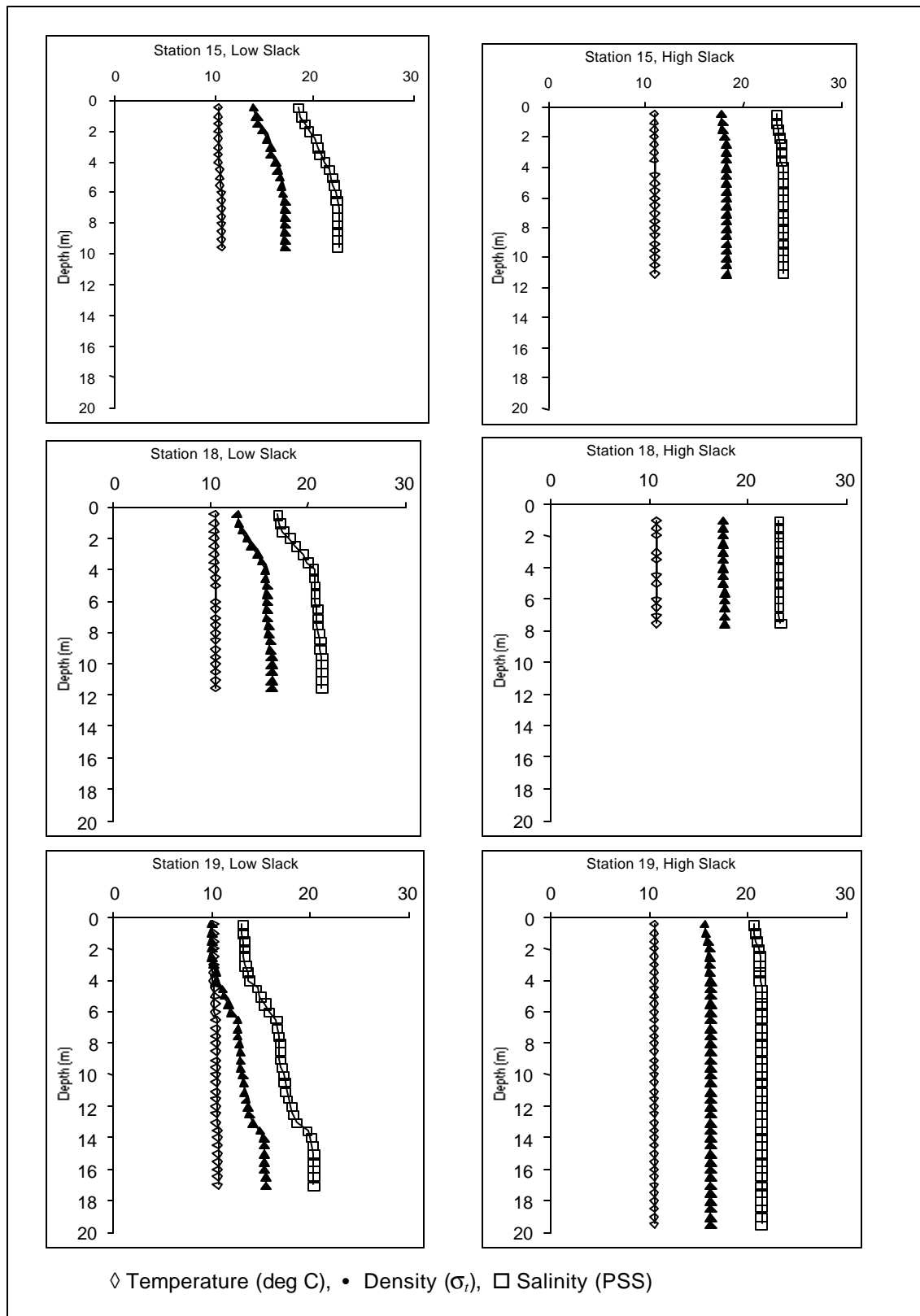


Figure 4-18. Temperature, density, and salinity profiles for stations in Naselle River Channel during low- and high-slack tides (Stations 15, 18, and 19)

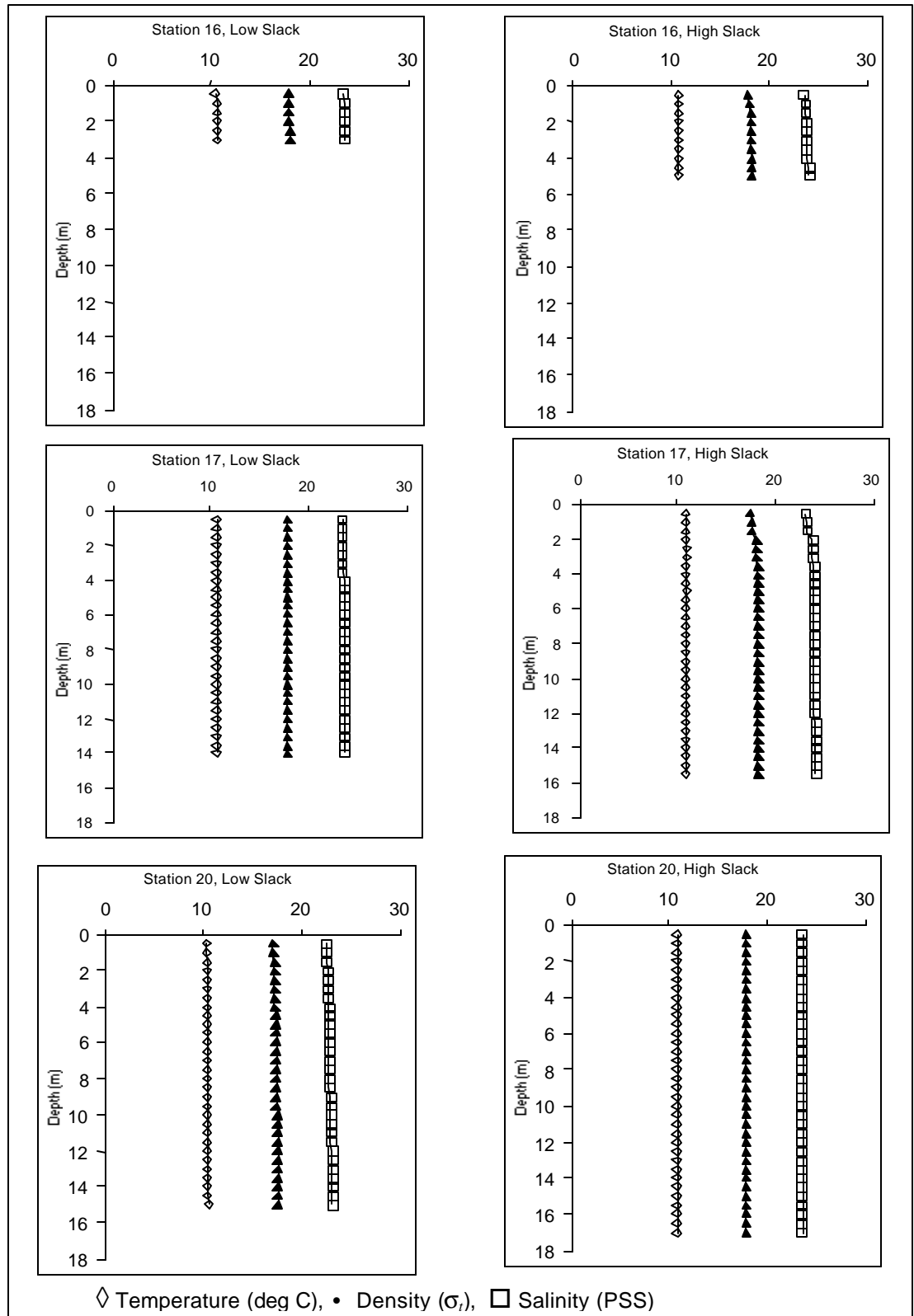


Figure 4-19. Temperature, density, and salinity profiles for stations in Nahcotta Channel during low- and high-slack tides (Stations 16, 17, and 20)

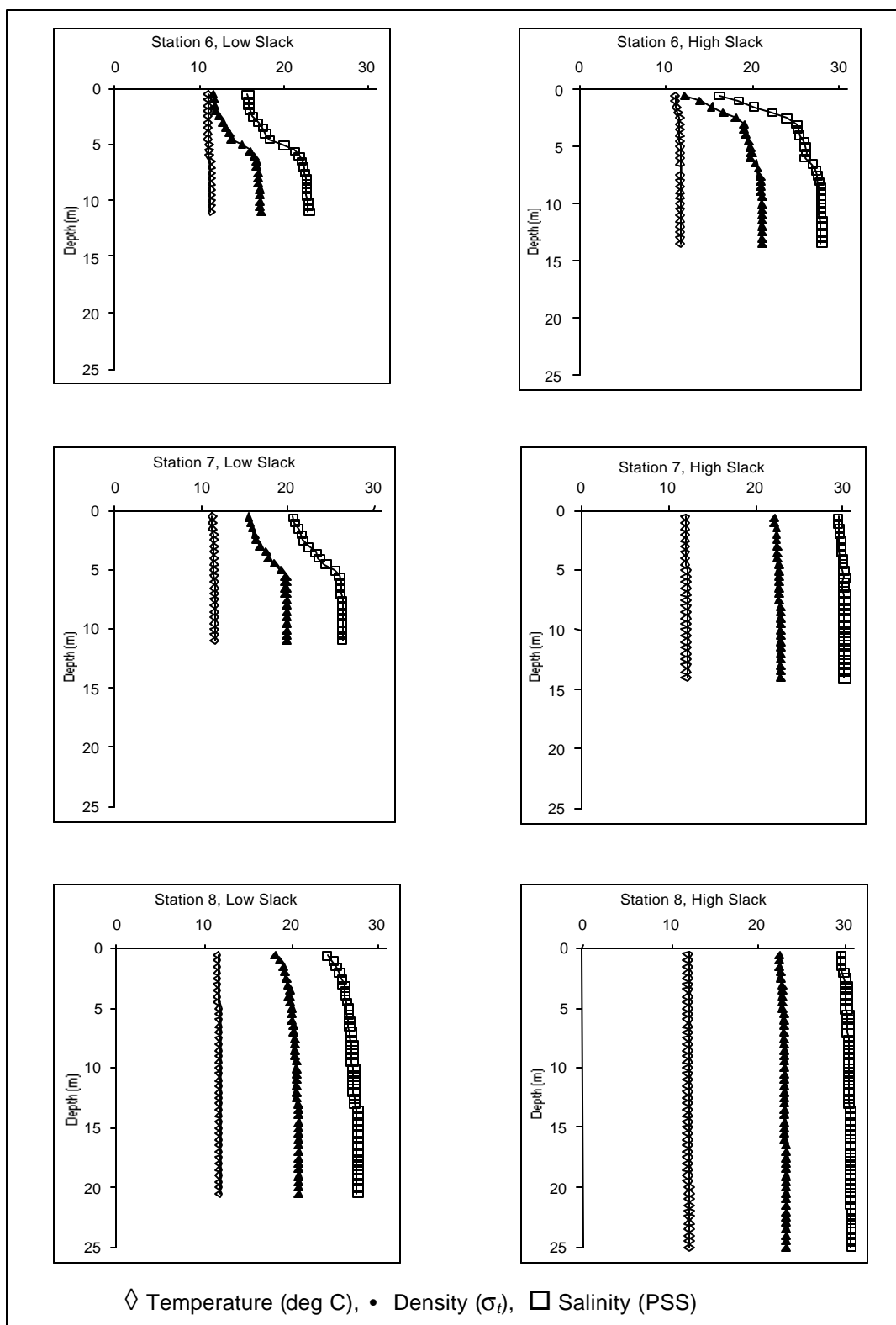


Figure 4-20. Temperature, density, and salinity profiles for stations in northern Willapa Bay during low- and high-slack tides (Stations 6-8)

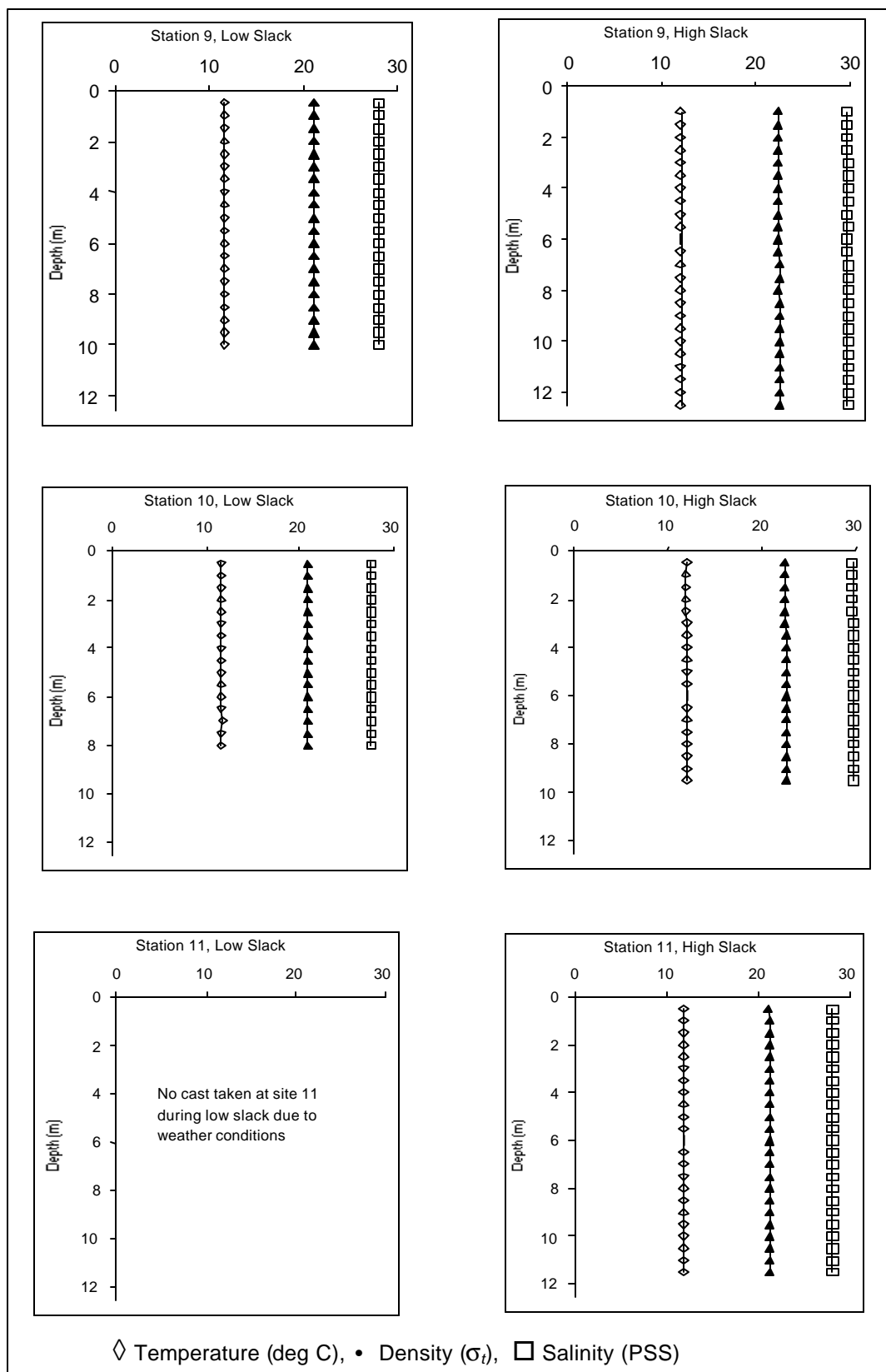


Figure 4-21. Temperature, density, and salinity profiles for stations in northern Willapa Bay during low- and high slack-tides (Stations 9-11)

## Data trends

Wind speed averages remained steady until November, when a series of storms caused the average of that month to increase greatly over previous months (Table 4-11, Figures 4-22 to 4-26). Similarly, wind gusts did not vary greatly from August through November, but reached a maximum of 23.5 m/sec during the storms. Net wind direction was from the northwest during August and September (308 and 307 deg true north, respectively), then shifted to the southeast during October and November (158 and 160 deg true, respectively).

Air temperature decreased steadily throughout the study period with the maximum occurring in October (Table 4-11, Figure 4-24).

Average barometric pressure did not vary significantly between August and November. The lowest reading in November corresponded with a storm and its associated strong winds.

**Table 4-11**  
**Meteorological Data Summary**

Parameter	Month	Average	Minimum	Maximum
Wind speed, m/sec	August	4.2	0.00	12.1
	September	3.9	0.01	11.3
	October	4.6	0.03	14.2
	November	6.6	0.60	17.0
Wind gusts, m/sec	August	5.4	0.0	14.7
	September	5.1	1.1	14.7
	October	6.0	1.1	17.9
	November	8.6	1.9	23.5
Air temperature, deg C	August	15.4	11.8	18.9
	September	13.8	10.1	20.4
	October	12.5	5.9	24.3
	November	10.3	6.7	13.3
Barometric pressure, mb	August	1,019.4	1,014.4	1,026.7
	September	1,015.1	1,008.7	1,022.4
	October	1,018.0	1,005.6	1,030.0
	November	1,014.2	1,000.6	1,021.9

## North Channel Borrow Site Monitoring

PIE has been monitoring changes in the North Channel Dredged Borrow Site that was used for placing material on the shore near SR-105. Monitoring has included monthly hydrographic surveys starting after completion of the dredging work. Analysis of the data was performed through bathymetric data contouring, plotting cross sections of the survey area, and calculating sedimentation rates and volumes. Survey methodology, survey data processing, and analysis are presented in this report. The North Channel Borrow Site is shown in Figure 4-27. This area is referred to as the Borrow Site.

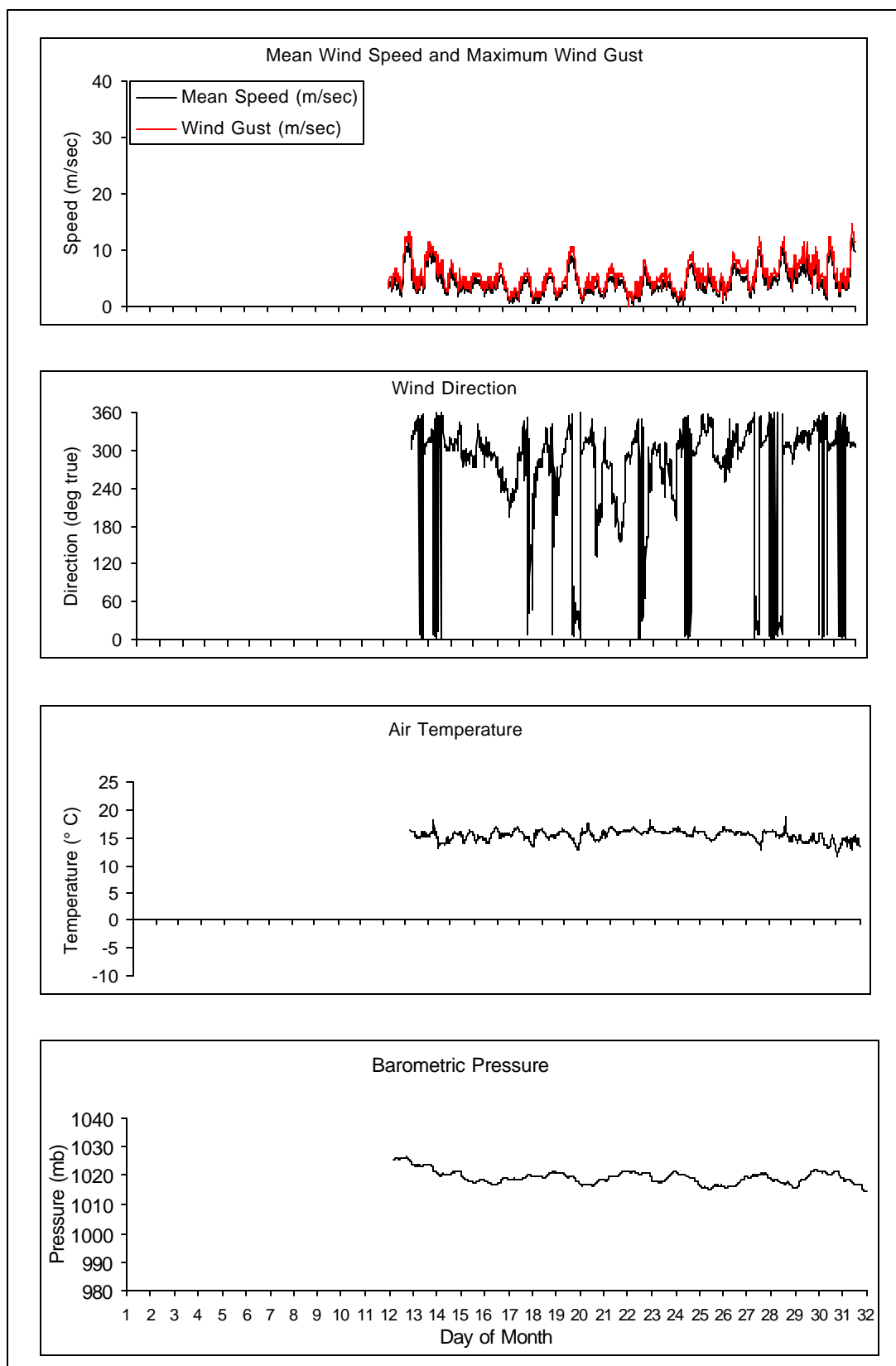


Figure 4-22. Meteorological data from central Willapa Bay, August 1998

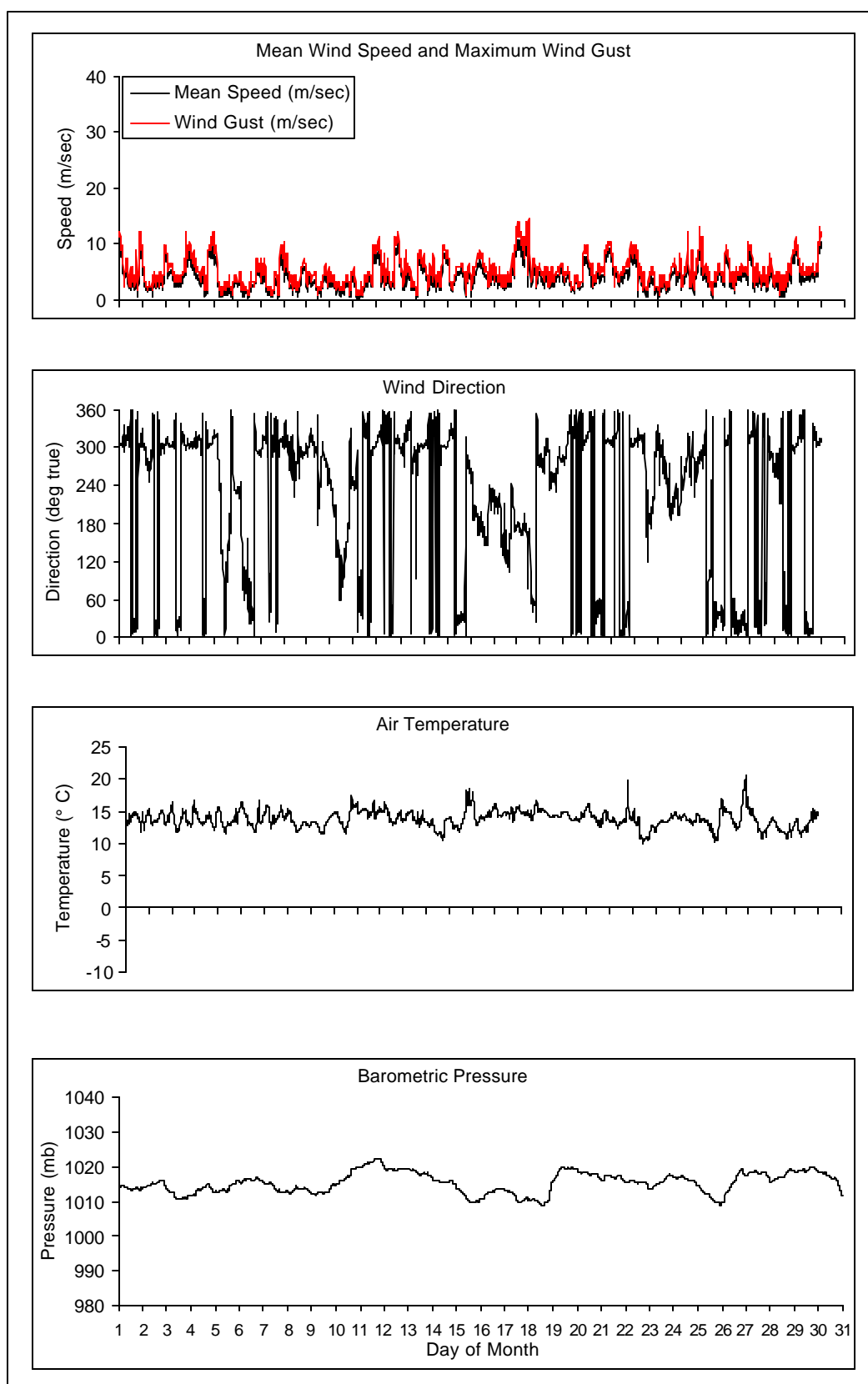


Figure 4-23. Meteorological data from central Willapa Bay, September 1998

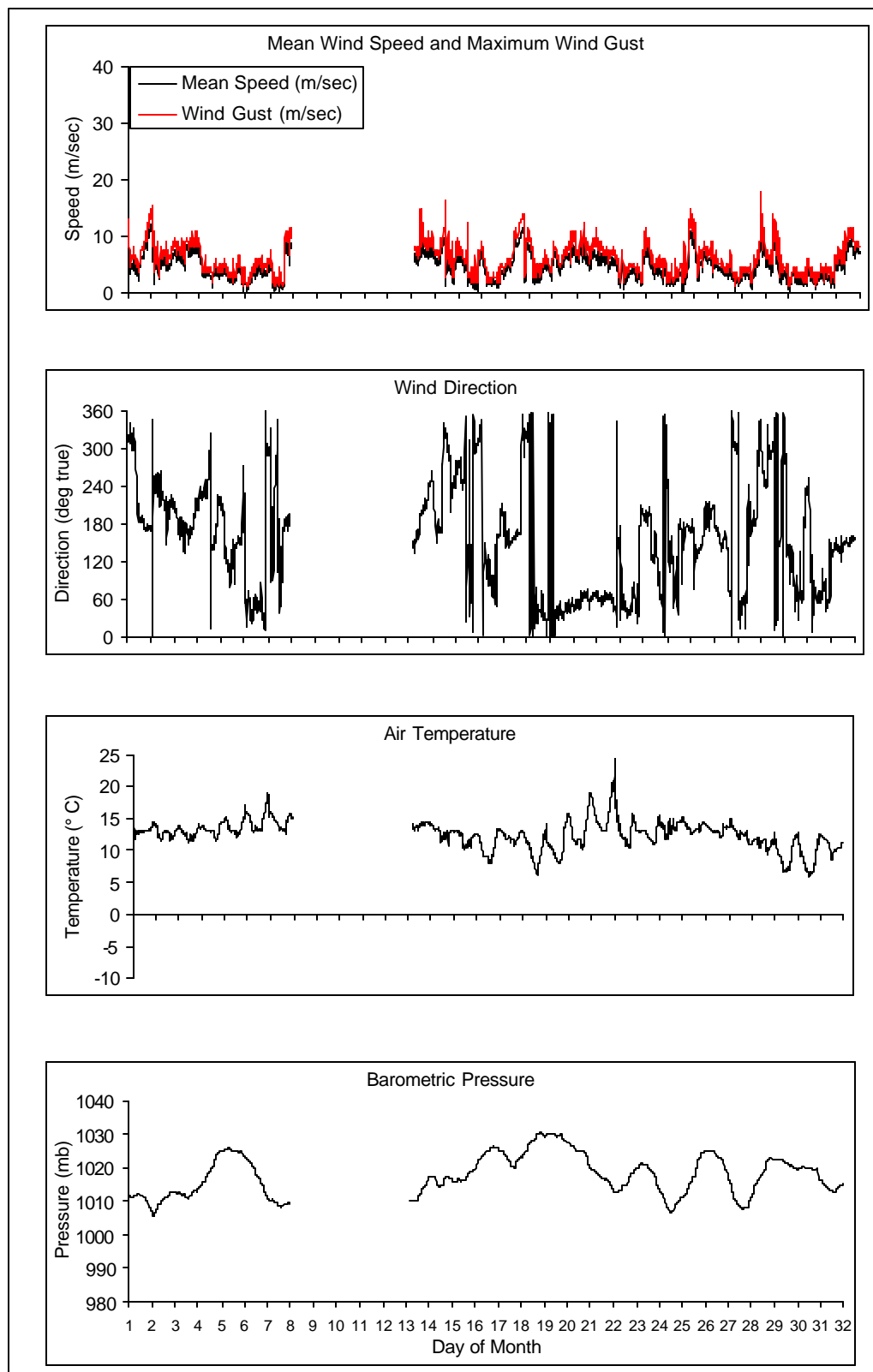


Figure 4-24. Meteorological data from central Willapa Bay, October 1998

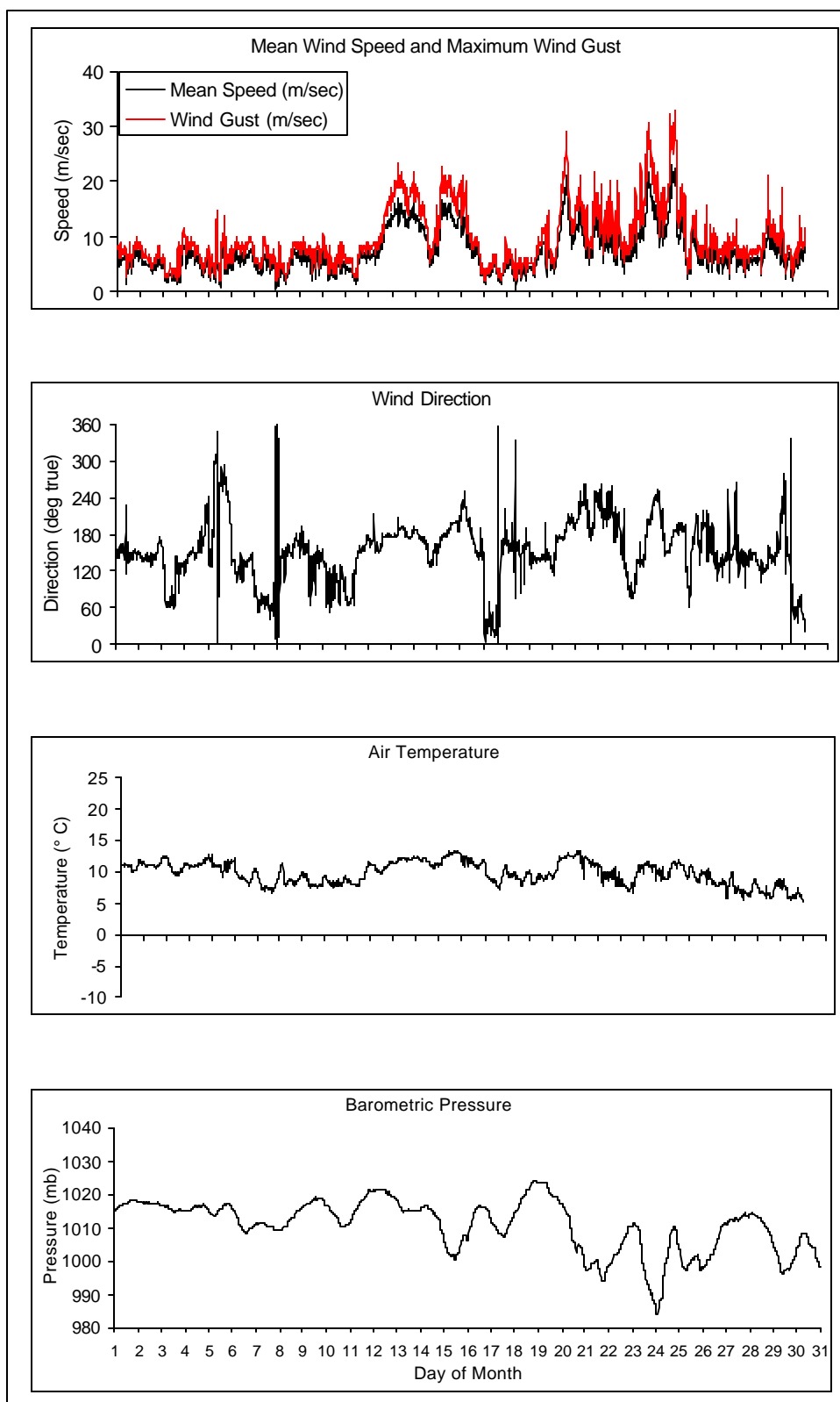


Figure 4-25. Meteorological data from central Willapa Bay, November 1998

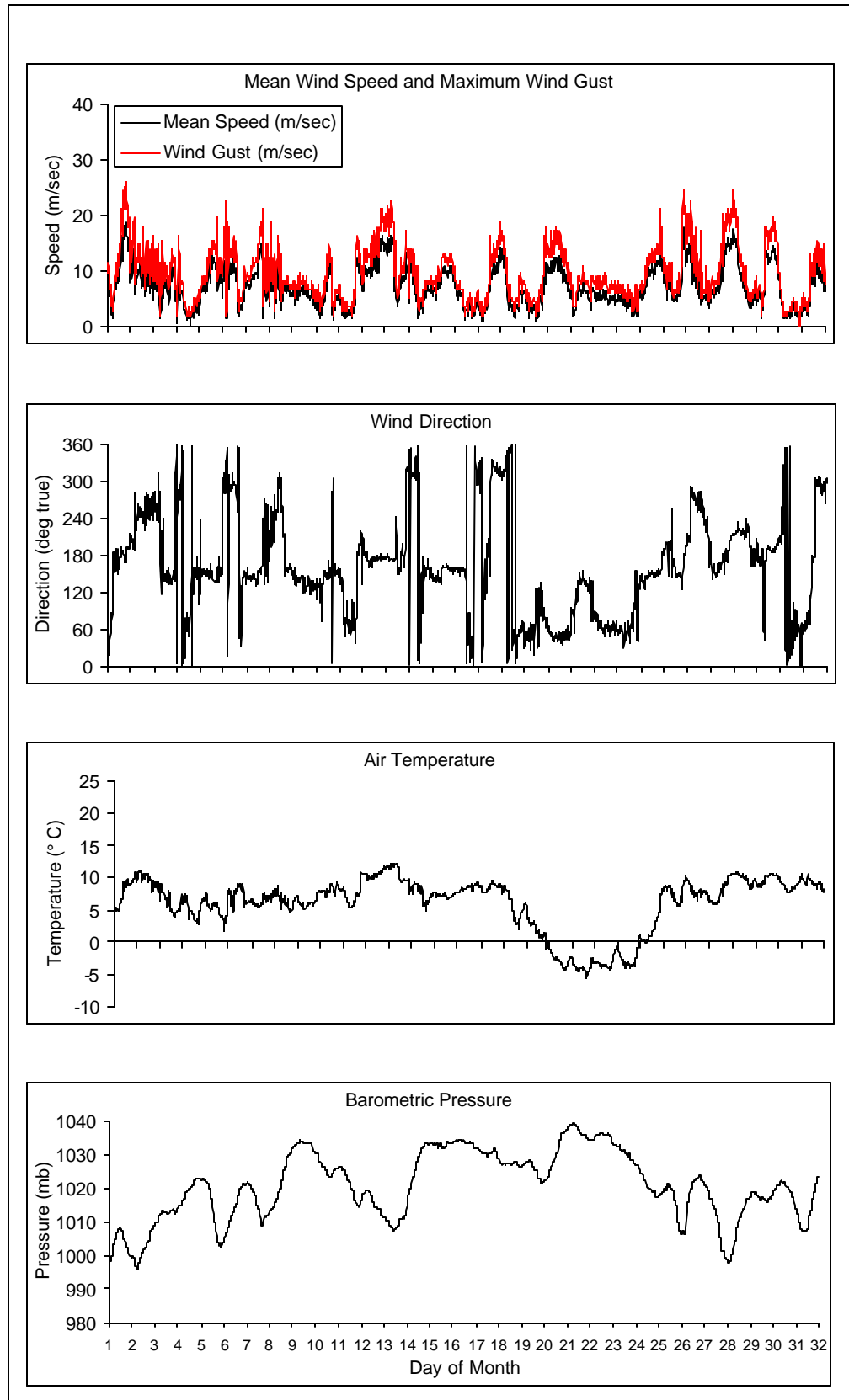


Figure 4-26. Meteorological data from central Willapa Bay, December 1998

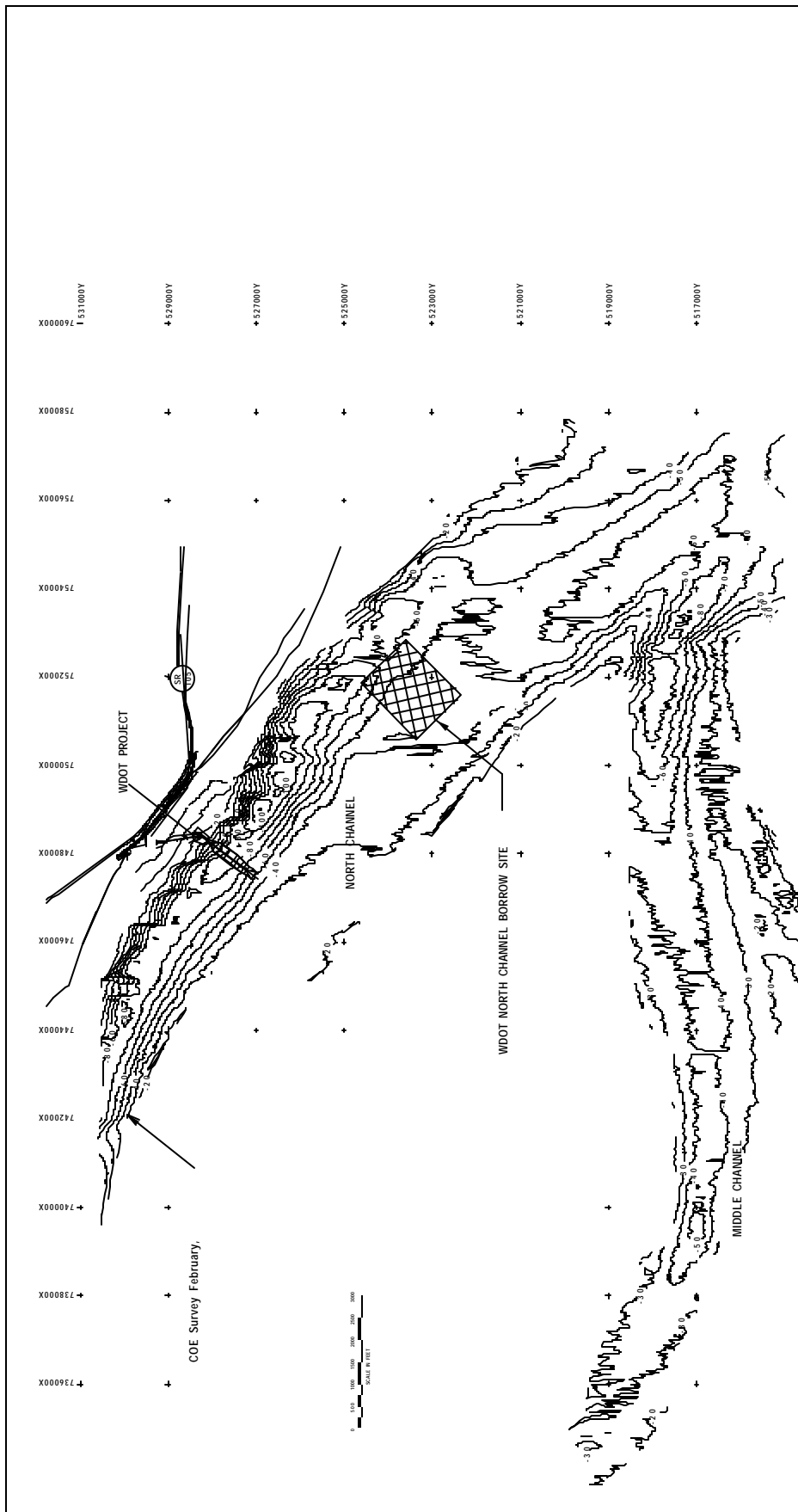


Figure 4-27. North Channel Borrow Site, Willapa Bay